Before the
Federal Communications Commission
Washington, D.C. 20554

In the Matter of	)	
	)	
Inquiry Regarding Software Defined Radios	)	ET Docket No. 00-47
	)	
	)	

COMMENTS OF VANU, INC.

Vanu, Inc. was formed in 1998 to explore the possibility of building software radios using object oriented computer languages running on general purpose processors. This approach to software radio was initially investigated by the founders of the company as the subject of the SpectrumWare Project at Massachusetts Institute of Technology, which began in 1995. The motivation for the SpectrumWare Project was that the rapid rate of improvement in microprocessor speed would soon bring the implementation of complex signal processing software systems into the realm of software. We believed that this paradigm shift in the implementation of wireless communications systems would enable, among other things, more efficient spectrum use, interoperation between historically incompatible radio systems and the much faster adoption of advances in digital communications.

While we continue to focus on object oriented software that is portable across multiple platforms and that supports independent specification and download of software radio applications, we have found that the extent to which we use software to implement signal processing distinguishes us from other radio developers. In the nomenclature of the SDR Forum, Vanu, Inc. develops software radios as opposed to software defined radios. The flexibility afforded by pushing the digitization closer to the antenna permits our products much greater degrees of freedom to adapt the nature of the signal processing performed by the radio. The Company is currently involved in commercial partnerships to develop software radio products and is participating in Step 2B of the armed services' JTRS program. We are also engaged in a cooperative agreement with the National Institute of Justice to develop a prototype software radio interoperability device targeted at law enforcement needs.

Summary

Vanu, Inc. recommends that the Commission consider the following amendments to its rules in order to enable and encourage the adoption of software radio technology, as this will enable more efficient use of spectrum and radios with superior capabilities.

- Allow radio manufacturers to follow the model of the personal computer industry by permitting de-coupling of hardware and software development.

This would entail permitting separate hardware and software approval as part of the equipment approval process. We advocate permitting such separate approval only for software radio architectures that employ an operating system that provides a complete abstraction barrier between the hardware and application software. As a software company, we do not advocate that changes to signal processing software ever be permitted to circumvent the approval process, no matter how small the change to the software may seem. Implementation of the necessary rule changes should take place within the next year to prevent slowing the commercialization of software radio.

- Address the difficulty of seeking experimental licenses for purposes of investigating software radio. Generally, we believe licenses that permit extremely low power experimentation in certain larger bands would be most appropriate. However, we also believe that higher power testing of shared infrastructure in rural areas will be appropriate shortly in order to demonstrate the efficacy of software radio in establishing interoperability and wireless telecommunications infrastructure in under-served areas. Implementation of the necessary rule changes should take place as quickly as possible in order to permit the necessary experimentation to support software radio product development.
- Finally, we recommend that the Commission license spectrum in a manner that permits dynamic modification of any attribute of the air interface, including the operators using the spectrum, subject to regulation necessary to prevent harmful interference. We firmly believe that the best means to encourage the development and investment in software radio is to mitigate risk for those developing the technology by continuing to show that the Commission is receptive to consideration of the necessary changes to regulations to foster this new technology.

In support of the above, we will first address the timeline for adoption of software radio technology, then address the desirability of de-coupling hardware and software development and the benefits of open architectures generally. We will close with a description of the benefits we expect to see arise out of the adoption of software radio technology over the next five years.

The state and trend of software radio technology

Infrastructure based on software radio can be deployed using existing technology. Software radio capabilities for handheld platforms will be phased in over the next five years.

It is important to consider separately the capabilities of, and, especially, the timelines for, portable software radio applications. Recent advances in A/D and D/A converters and microprocessors have made software radio practical for fixed infrastructure applications such as basestations and fixed wireless terminals. Power dissipation remains the primary limitation for handheld software radio platforms, and

advances in low power processors; memory and A/D and D/A converters are required to make handheld software radio a practical reality. Ultimately, the proliferation of software radio platforms and infrastructure will enable a wide range of new capabilities. In the mean time, there are many new capabilities, such as interoperability, beamforming and rapid adoption of technology advances through software upgrades that are enabled by software defined radio infrastructure alone. As handheld software radio platforms come to market, the combination of handheld infrastructure platforms will enable new capabilities such as dynamic spectrum management, more efficient spectrum utilization and dynamic adaptation to traffic and environmental changes.

Most functions performed by wireless communication infrastructure today can be implemented using software radio technology. The power dissipation constraints on handheld platforms permit a smaller subset of the functions to be implemented in software today, but this subset will expand as low power processing technology advances. Table 1 shows the current capabilities for infrastructure and handheld platforms and Table 2 illustrates the estimated capabilities for the implementation of key functions in software 5 years from now. All functions that are listed in software implemented are capable of being downloaded to the software defined radio platform as aftermarket enhancements.

Platform	**Current Capability**		
Infrastructure	*Hardware*	*Software Controlled*	*Software Implemented*
	Antenna	-RF tuning -IF conversion -Output Power	-Channel selection -Chip rate processing -Mod/Demodulation -Symbol slicing -Coding -Link layer processing
Handheld Platform	*Hardware*	*Software Controlled*	*Software Implemented*
	Antenna	-RF tuning -IF conversion -Output Power -Channel Selection -Chip Rate Processing	-Mod/Demodulation -Symbol slicing -Coding -Link layer processing

Table 1: Current software functionality

Platform	**Predicted Capability in 5 years**		
Basestation	*Hardware*	*Software Controlled*	*Software Implemented*
		-RF tuning -IF conversion -Output Power -Smart Antenna	-Channel selection -Chip rate processing -Mod/Demodulation -Symbol slicing -Coding -Link layer processing
Handheld	*Hardware*	*Software Controlled*	*Software Implemented*
	Antenna	-RF tuning -IF conversion -Output Power -Bandwidth	-Mod/Demodulation -Symbol slicing -Coding -Link layer processing -Channel Selection -Chip Rate Processing

Table 2: Predicted software functionality in 5 years

For infrastructure platforms, the primary limitation is the cost of tunable wideband RF front-ends that cover a broad range of RF frequencies. Currently, RF front-ends are designed to cover bands that are regulated for certain services. For example, chips sets are available that cover the cellular and PCS bands. Given the way spectrum is currently regulated, there is no commercial incentive to build such front-ends, and what is available is extremely expensive.

For handheld platforms, there are more significant limitations related to power dissipation. Development of low power A/D and D/A converters, memory and processors are key advances that are necessary for the realization of handheld software radio. Low power A/D and D/A converters exist for narrow band applications, but looking forward to 3G and emerging wireless applications it will be necessary to digitize wider bands. Memory is a significant consumer of power. In some PDAs today the memory consumes more power than the processor. Looking ahead, software radio devices will contain significant amounts of memory and low power, high density memory devices will be essential for handheld software radios. Recent advances in low power processors, such as the Intel StrongARM, hold tremendous promise for handheld software radio. However, these processors currently have neither the computational power nor the power dissipation characteristics needed for handheld software radio platforms.

Benefits of software

The greatest need for a software radio system is in the public safety markets, and current software radio infrastructure can be used to address the interoperability problems that plague public safety organizations. Emerging wireless network systems such as LMDS, MMDS and various metropolitan area network systems could benefit greatly from software radio technology.

Software radio enables a wide range of new capabilities including interoperability and better spectrum utilization through techniques such as dynamic spectrum allocation. These capabilities are discussed in the following sections.

Interoperability

Software radio is ideally suited to the task of enabling interoperability between equipment and services using different transmission protocols. Since a true software radio implements all signal processing functions, including channel selection and modulation in software, the system can be re-programmed to receive and transmit on any standard, thus enabling interoperability between any two systems.

Software radio can facilitate interoperability in two different ways:

1. A software radio including software radio infrastructure, can perform a translation between two incompatible air interfaces by receiving a signal transmitted using air interface and immediately retransferring the signal using another air interface, and vice versa.
2. A software radio handset can run the appropriate software application to enable interoperability with another device.

The advantage of the first method is that it can facilitate interoperability between legacy handsets, that is, handsets without software radio capability. The drawback of this method is threefold; it involves additional latency to the communications system, (usually on the order of 10 to 100 milliseconds), it places a greater processing load on the system performing the translation, and it uses two communication “channels” simultaneously to establish one communication link. The second method overcomes these limitations, but can only be used when at least one of the parties to the communication employs a software radio.

Software radio can eliminate most of the interoperability problems facing public safety agencies today. Vanu, Inc. is currently working with the National Institute of Justice (NIJ) to create a prototype software radio system that enables communications interoperability between agencies using different radio systems and operating in different frequency bands. Based on our work with the NIJ to date, the only barrier to solving some of the interoperability problems in the near term is the use of the closed proprietary standards by some radio manufacturers.

Looking to the future, software radio will alleviate interoperability problems by reducing the role of standards. The importance of standards is primarily driven by the desire to have multiple manufacturers build equipment that can interoperate. In a software radio, the ability to interoperate is completely defined by the software. If a user has the ability to download new software radio applications (an application represents an entire air-standard), then they also have the ability to interoperate with anyone else using that standard. In this sense uniformity of standards is not an issue, as a single standard is not needed to insure interoperability. Software radios permit standards to evolve much

more quickly with out experiencing the interoperability problems normally associated with changing standards.

What does need to be standardized is a method of specifying and downloading new software radio applications. A standardized way, such as a description language, for specifying radios is an essential component of any software radio system. In addition, a protocol for determining the standard that is in use, and for requesting a software download if the required application is not resident, is required to insure interoperability.

Using this software download capability, software radio is well suited to facilitate transitions between standards, bands and channel widths. However, this type of transition requires software radio handsets that can be re-programmed in this manner. Thus the facilitation of these transitions will not be practical until software radio handsets become commercially viable.

Improving spectrum efficiency and spectrum sharing

Software radio can improve the efficiency of spectrum usage through the rapid incorporation of new technology via software downloads and through the ability to support dynamic spectrum management.

Software radios can download new functions and standards that are more spectrally efficient. For example, new systems incorporating advances such as turbo coding or more efficient modulation techniques can be downloaded to existing platforms, rather than having to wait for the next standards evolution to be incorporated. Similarly, advances in vocoders enabling narrower voice channels can be downloaded enabling a particular spectrum allocation to support more users.

Software radio also will enable dynamic spectrum management, which will be a tremendous step forward in spectrum utilization. Since software radios can be re-programmed to use a wide range of RF frequencies, unused spectrum can be leased on an as needed basis, and the lessee can program their radio system to use whatever spectrum they were able to acquire. Services that are under-subscribed can lease out additional spectrum capacity, earning revenue for them, and providing the public with better use of the spectrum resource. Similarly, cellular systems that are largely dormant at night, can temporarily lease spectrum to wireless ISP providers to backhaul large amounts of data during these off-peak hours.

While software radios can certainly improve spectrum usage by independently locating free spectrum and dynamically allocating bandwidth, it is important to have systems and procedures in place to avoid interference with critical legacy frequency allocations such as air-traffic control and public safety frequencies. There are several ways in which this could be achieved. The Commission or its appointees or licensees could act as brokers for spectrum in a given geographic region. This broker would perform in a largely automated, on-line function, accepting requests for frequency usage and allocating frequencies based on a number of parameters including priority (e.g.

public safety systems during a disaster) and cost (how much each bidder is willing to pay). The broker function would insure that unauthorized units do not use critical frequencies. One advantage of this approach is that the Commission could now receive ongoing revenue, at market rates, for use of the. A secondary market is an important part of this system. If a party leases spectrum but finds its system load lower than projected, it should be able to re-sell its lease to re-coup the investment and enable better use of the spectrum by the public.

Another approach would be to have radios scan for available spectrum. The advantage of this approach is that it does not rely on a centralized authority. To insure protection of certain frequencies, each radio would be required to have a geographically based table of restricted frequencies. Assuming the radio has GPS capabilities, it can use the position information to determine the set of locally restricted frequencies, and then scan allowable frequencies to determine free spectrum regions. The table would have to have a lifetime associated with it, forcing the radio to download table updates periodically. Preliminary estimates suggest that such a table could be small enough to be reasonably stored on a handheld device.

Equipment approval process

If done improperly, the equipment approval process could reduce many of the benefits of software radio, stifle innovation and result in more expensive radios. To create a dynamic marketplace where new applications, standards and algorithms can be downloaded into a radio, it is necessary to have a system in place that allows certification of the software independent of the hardware. One key aspect to the de-coupling is embracing an operating system abstraction. The operating system sits between the hardware and the software. Any hardware that supports the operating system will run any application that is compliant with the operating system. Without independent verification of the hardware and the software, the most likely scenario is that the hardware vendor becomes the sole supplier of software for their platform. This will reduce competition, which will in turn slow innovation and increase the costs of software radio systems.

Internally, a software radio looks more like a PC than a conventional radio. Lessons learned in the standardization and innovation in the PC market provide important lessons for the emerging software radio market. One of the key factors that enabled the rapid pace of innovation and competition in the PC marketplace is the abstraction, provided by the operating system, between the software and hardware. This enables any software vendor to write software with the knowledge that it will work on any PC platform. If each software application had to be certified with each manufacturer's PC, there would be far fewer platforms and applications available, and the lack of competition would have resulted in considerably more expensive PCs.

Clearly, the operating system is a critical piece of the system. We recommend the adoption of Linux as the operating system for software radios. Since Linux is open source, no single vendor will be able to dominant the software radio operating system, and thus the software radio industry. Furthermore Linux can be easily and rapidly

improved to meet the needs of software radio systems. Our work has shown that Linux is a viable operating system for basestation software radio systems, and recent work on embedded Linux indicates that it will be suitable for handheld platforms as well. The Linux API can be extended to support interfaces for software radio that will facilitate the independent testing of hardware and software components.

The operating system alone is not enough. The software applications must be architected in a manner that permits verification. It may not be possible to permit minor revisions to be released without certification, since even a minor change can introduce new bugs that might affect critical functions such as the frequency that the device transmits on. This makes it all the more important to separate the software and hardware testing. The need to certify every new upgrade with every piece of hardware on which it might run would be prohibitive. This certification does not have to be a government function, and could be handled by a third party, much like U.L. for electrical equipment.

The hardware compliance testing must be done in such a way that it insures enforcement of key parameters such as maximum radiated power and RF frequency, as well as supporting security functions for authentication and encryption.

The software download process must guard against the proliferation of uncertified software, and prevent certain applications, such as law enforcement radio applications, from being run on radios not approved for these purposes. Both of these problems can be addressed through the use of cryptographic authentication technology. The certifying body should sign the code, and part of the hardware certification would be to prevent execution of unauthenticated code. In addition, each radio should have a unique public key associated with it, permitting application and frequency usage to be controlled on a per radio basis. Although this imposes the overhead of a public key management structure, public key cryptography is the only reasonable tool with which to attack this problem. An offsetting benefit to this approach is that commercial radios become a subset of radios used by government agencies insofar as they are radios that simply are not permitted to run certain applications. Significantly, commercial and government radios could be manufactured identically and distinguished in software.

Recommendations

In summary, Vanu, Inc. believes that current software radio technology can be practically applied to infrastructure applications today, and that software radio handheld devices are still several years in the future. However, software radio infrastructure alone can provide many benefits. It can provide a solution to many existing interoperability problems, especially in the public safety arena and provide a path for rapid evolution of technology through software upgrades. The upgrades can take the form of new services or new algorithms, such as beamforming, that improve spectrum utilization. As software radio handsets become feasible, a wide range of new services and applications, such as dynamic spectrum allocation, become possible. These applications will greatly improve spectrum utilization, eliminate interoperability problems and enable rapid evolution of technology through software upgrades.

We believe that it is important to for the commission to consider rule changes that not only encourage the types of capabilities enabled by software radio, but also rule changes that remove some of the current regulatory barriers that hinder the design, testing and production of software radio products. Specifically, we encourage the commission to take the following steps:

- Allow radio manufacturers to follow the model of the personal computer industry by permitting de-coupling of hardware and software development. This would entail permitting separate hardware and software approval as part of the equipment approval process. We advocate permitting such separate approval only for software radio architectures that employ an operating system that provides a complete abstraction barrier between the hardware and application software. As a software company, we do not advocate that changes to signal processing software ever be permitted to circumvent the approval process, no matter how small the change to the software may seem. Implementation of the necessary rule changes should take place within the next year to prevent slowing the commercialization of software radio.
- Address the difficulty of seeking experimental licenses for purposes of investigating software radio. Generally, we believe licenses that permit extremely low power experimentation in certain larger bands would be most appropriate. However, we also believe that higher power testing of shared infrastructure in rural areas will be appropriate shortly in order to demonstrate the efficacy of software radio in establishing interoperability and wireless telecommunications infrastructure in under-served areas. Implementation of the necessary rule changes should take place as quickly as possible in order to permit the necessary experimentation to support software radio product development.
- Finally, we recommend that the Commission license spectrum in a manner that permits dynamic modification of any attribute of the air interface, including the operators using the spectrum, subject to regulation necessary to prevent harmful interference. We firmly believe that the best means to encourage the development and investment in software radio is to mitigate risk for those developing the technology by continuing to show that the Commission is receptive to consideration of the necessary changes to regulations to foster this new technology.